INTEGRATED TRANSMITTERS AND LONG-WAVELENGTH VCSELs

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13. ABSTRACT (Maximum 200 words)

The objective of this program is to develop InP-based monolithically integrated transmitters, including internal (current) and external modulation. The basic issues involved in such integration and operation of the individual devices will be explored both theoretically and experimentally. Thus, intrinsic and extrinsic factors that limit internal and external modulation, propagation and scattering of light in guided structures and through mirrors, and circuits, materials and lithography issues to develop high-frequency (>30 GHz) transmitters will be explored. Integrated chips with driver circuits and guided wave elements will be developed and tested.

At the same time we are also developing novel top- and edge-emitting microcavity laser structures in which zero or very low threshold curents are expected due to phonon confinement. Preliminary results, both theoretical and experimental, are very encouraging, and we envisage that these low threshold, high frequency devices will be extremely useful for chip-to-chip and array-based optical interconnects.

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Objective

To design, fabricate and characterize microcavity lasers and LEDs and 1.55μm monolithically integrated transmitters.

Progress

1. 1.55 μm InP-based Photonic Crystal microcavities

1.1 Introduction

Microcavities with dimensions on the wavelength scale are being extensively investigated due to their ability to exhibit enhanced spontaneous emission, directional output and single-mode operation. Photonic crystals with single or multiple defects have emerged as the preferred way to obtain such microcavities[1-3]. We have designed and fabricated a 1.55μm electrically injected photonic crystal microcavity using an InP-based heterostructure.

1.2 Fabrication and Design

The InP-based laser heterostructure is grown by MOCVD. It consists of an n+ InP contact layer, an n-type bottom InP/InGaAsP distributed Bragg reflector (DBR) mirror, an undoped 1.55 μm λ-cavity with 9 pseudomorphic quantum wells in the middle and p-type InGaAsP and contact layers on the top. A p-type AlInAs layer are also inserted on top of the cavity region for eventual lateral wet-oxidation during the processing of the device. The photoluminescence emission peak from the quantum wells is observed at 1.55 microns. Standard oxide-confined VCSEL process steps were used in the device fabrication with a combination of optical lithography, dry and wet etching, metallization and polymide planarization.The 2D photonic crystal formation is achieved afterwards using the Leica/Cambridge EBMF ebeam lithography tool, a metal-on-polyimide process[4] to reverse the ebeam pattern followed by anisotropic high temperature dry etching of the pattern into the InP heterostructure using a Plasmaquest ECR[5] source. The deep etch goes through the entire cavity region. A single or multiple defects in the center define the lambda-sized microcavity which was designed with the photonic bandgap encompassing the peak emission wavelength of 1.55micron.

A photo micrograph of the top of the device with contact metallizations and SEM micrographs of the topview and cross-section of the 2D photonic crystal are shown in figures 1 and 2. The active area aperture, created by the single defect is 0.8microns. This aperture is surrounded by 65 periods of the photonic crystal, having an extent (radius) of 30 microns.

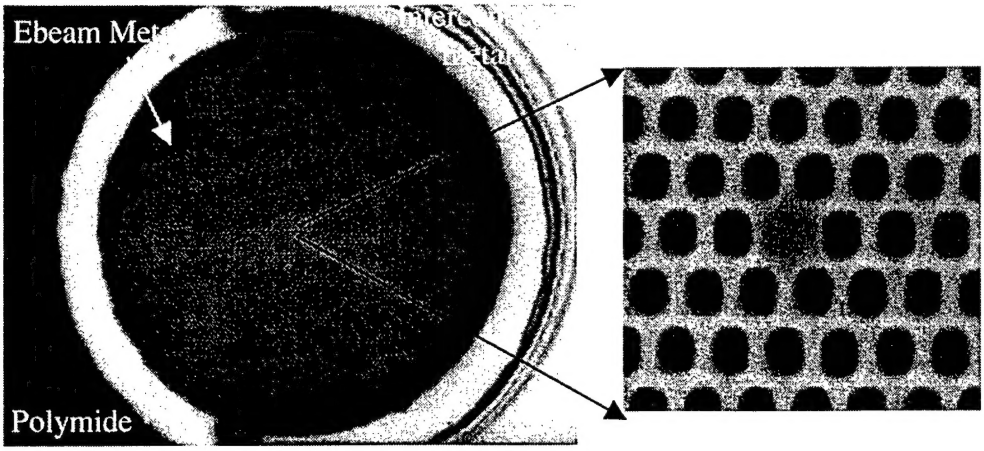

Fig 1. Photomicrograph of the topview of surface emitting device after standard VCSEL process with single defect photonic crystal ebeam pattern integrated in the center of the aperture. Top view SEM of single defect photonic crystal after ebeam patterning, pattern reversal and deep etching with hole radius of 0.2μm and pitch of 0.6 μm a depth of 1.46μm

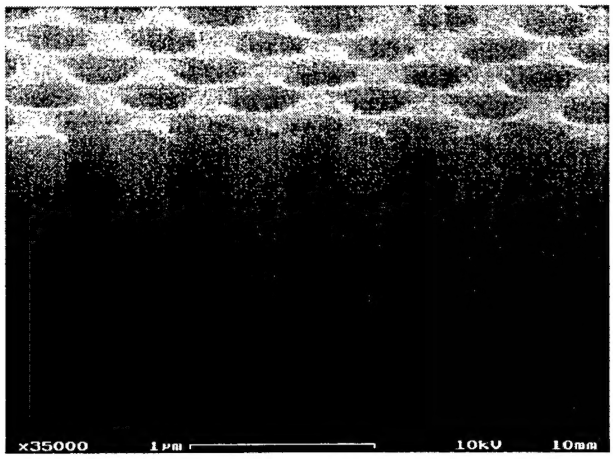

Fig 2. Cross Section SEM of InP photonic crystal after ebeam patterning, pattern reversal and deep etching with the Plasmaquest ECR source

1.3 Future Work

Initial L-I measurements were taken before the 2D photonic crystal formation. Measurements of the device with 2D photonic crystal microcavity are currently in progress.

2. Long-wavelength vertical cavity surface emitting lasers on patterned GaAs substrates

2.1 Summary

The progress of the project on long-wavelength vertical cavity surface emitting lasers (VCSELs) on patterned GaAs substrates is reported next. First, the prospects and advantages of the present scheme on other long-wavelength VCSELs is reviewed and restated. Second, the design and layout of the novel VCSELs are discussed, followed by the recent progress in the fabrication of the devices. Finally, the current and future phases of the project are shortly outlined.

2.2 Introduction

Long-wavelength (1.30-1.55 μm) VCSELs are one of the most promising light sources for long-haul fiber optic communications. Conventional VCSELs with InGaAsP wells grown on InP substrates utilize lattice-matched InP/InGaAsP (or InAlGaAs) distributed Bragg reflectors (DBRs), the refractive index contrast of which is so low that over 40 DBR periods is required to obtain a high reflectance in the vicinity of the lasing wavelength. Consequently, epitaxial and processing challenges arise, and the high resistivity of the thick DBRs strongly degrades the performance of these VCSELs.

Higher refractive index contrasts can be achieved with amorphous dielectric mirrors (e.g. ZnSe/MgF) or by fusing AlGaAs/GaAs DBRs to InP-based InGaAsP active layers. However, dielectric mirrors suffer low electrical conductivity, while the fusing technique has reliability concerns at the fused junctions and is not easily applicable to large wafers. To overcome many of the mentioned challenges, growth on patterned substrates has been pursued in this group.

AlGaAs/GaAs system is largely lattice-mismatched to InP/InGaAsP and the critical thickness is too low to grow DBR layers on InP substrates. Theoretical and experimental results, however, have proved that critical thickness is remarkably higher, and the misfit dislocations are considerably lower, if lattice-mismatched materials are grown on patterned substrates (mesas or grooves). Our group has previously realized the growth of high quality GaAs/AlAs DBRs on top of patterned InP-based quantum well (QW) structures [6], and has also demonstrated 1.55 μm InP-based VCSELs with short-stack defect-free GaAs-based top DBRs [7]. These have motivated the design, fabrication, and realization of InP/InGaAsP active layer VCSELs with AlGaAs/GaAs DBRs grown on patterned GaAs substrates. This novel scheme envisages many advantages to the previous work: (a) short-stack AlGaAs/GaAs DBRs can be grown not only for top p-doped DBRs, but also for the bottom n-doped distributed mirror; (b) growth can be accomplished in one step on a patterned substrate, i.e., no regrowth is required; (c) Misfit dislocations at the regrown interface are avoided.

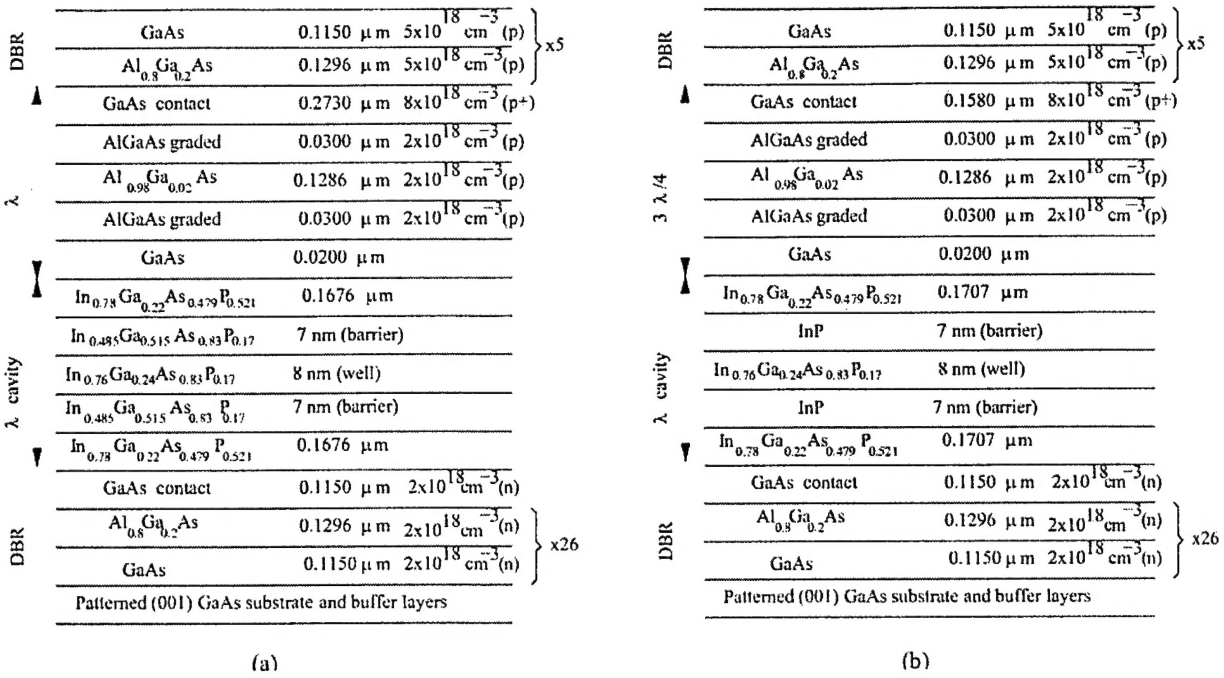

Figure 3: The schematic of patterned substrate VCSELs: (a) with InGaAsP barrier QWs; (b) with InP barrier QWs.

2.3 Design

1.30- and 1.55-μm VCSELs with AlGaAs/GaAs DBRs and InGaAsP QWs were designed by an in-house two-dimensional optical mode simulator, which calculates different transverse electric (TE) and transverse magnetic (TM) modes of semiconductor waveguide structures. Two variations of devices with different barriers, namely InP and $In_{0.485}Ga_{0.515}As_{0.83}P_{0.17}$, were simulated. The layout of the two type of VCSELs are shown in Fig. 3 (a) and (b)[1]As can be seen, both VCSELs consists of 26 periods of $Al_{0.80}Ga_{0.20}As$/GaAs quarter-wavelength λ n-doped DBRs, followed by a λ-cavity active layer with eight $In_{0.76}Ga_{0.24}As_{0.83}P_{0.17}$/$In_{0.485}Ga_{0.515}As_{0.83}P_{0.17}$ or $In_{0.76}Ga_{0.24}As_{0.83}P_{0.17}$/InP QWs. Similar to the bottom mirror, the top one consists of five periods of λ/4 $Al_{0.80}Ga_{0.20}As$/GaAs DBRs, while a λ-thick region[2] is placed between the top DBR and the λ-cavity active region. The extra layers are for p-contact purposes, as well as to embed a high mole fraction $Al_{0.98}Ga_{0.02}As$ layer graded to GaAs from both sides. The $Al_{0.98}Ga_{0.02}As$ layer should be selectively oxidized during the processing of the VCSELs,

[1] Similar structures were also designed for 1.3μm VCSELs, but are not presented herein.

[2] As observed in Fig. 3(b), the thickness had to be modified to 3λ/4 in order to obtain the desired optical mode profiles for the case of InP barrier devices.

primarily to confine the injection current to the active region and prevent shunt current between the ohmic contacts.

With respect to the basic design constraints required for device operation, other parameters such as various thicknesses and mole fractions were varied such that the TE_{00} mode is the dominant mode with a peak field intensity in the QWs region, while all the other TE and TM modes have negligible intensity in that region. The TE_{00} mode amplitudes in the growth direction for both devices of Fig. 3 are shown in Fig. 4 with the profile of refractive index along the same axis.

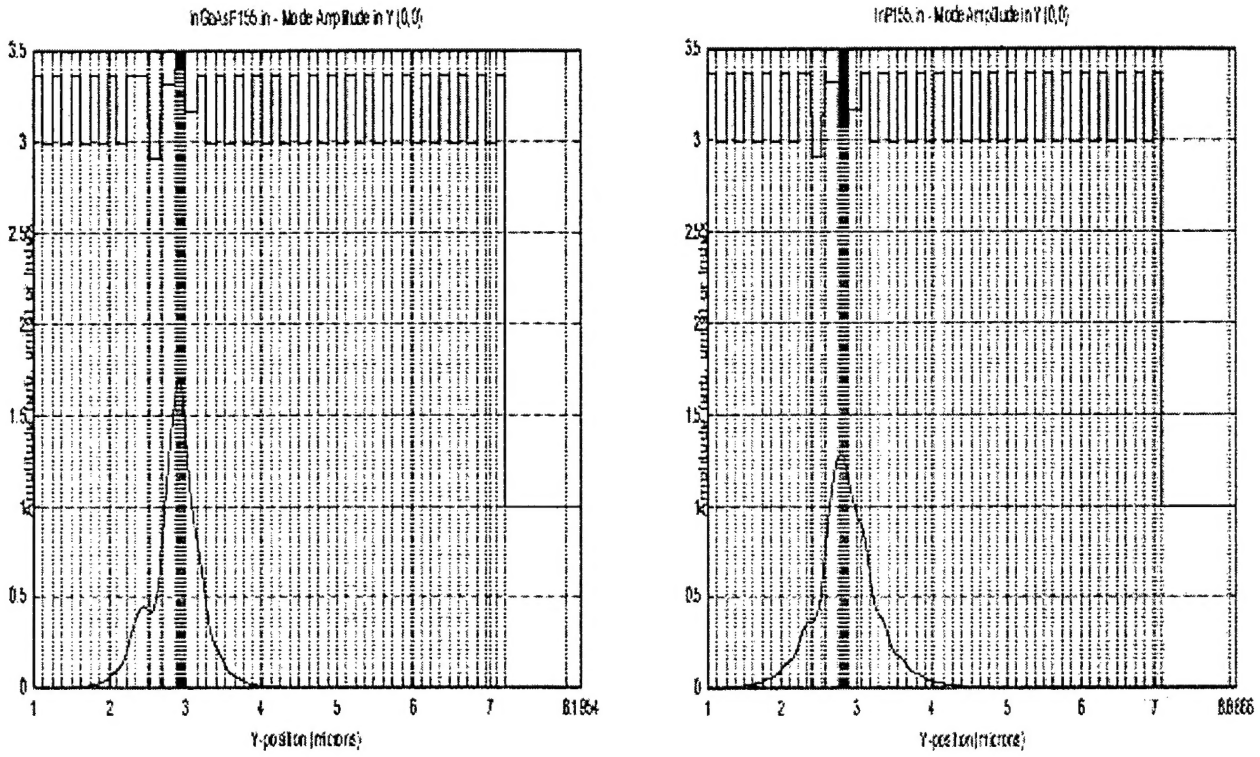

Fig. 4: The TE_{00} mode field intensity profile (a.u.) and the profile of the refractive index along the growth direction for VCSELs (a) and (b) in Fig.3.

2.4 Fabrication

The fabrication of the VCSELs was planned in four phases, the first of which is already accomplished and the others are underway.

Phase I of the fabrication was the growth of n- and p-doped DBRs on non-patterned GaAs substrates. This phase is primarily for the calibration of the growth conditions for optimum DBR structures. The measured reflectances for 12 periods of n-doped DBR and five periods of p-doped DBR is presented in Fig. 5. The n-doped DBR shows excellent wavelength selectivity with a maximum reflectivity of 87% at 1559 nm and a full-width-

at-half-maximum of 172 nm. The top DBR sample also includes the 3λ4 oxidation layer of the VCSELs with InP barriers. The graded AlGaAs layer comprises alternating layers of $Al_{0.80}Ga_{0.20}As$/GaAs, i.e., chirped superlattice structures. As can be observed in Fig. 5(b), the maximum reflectivity in this case is about 50 nm more than what expected, which will be recalibrated in the growth of the full laser structure in Phase III, as follows.

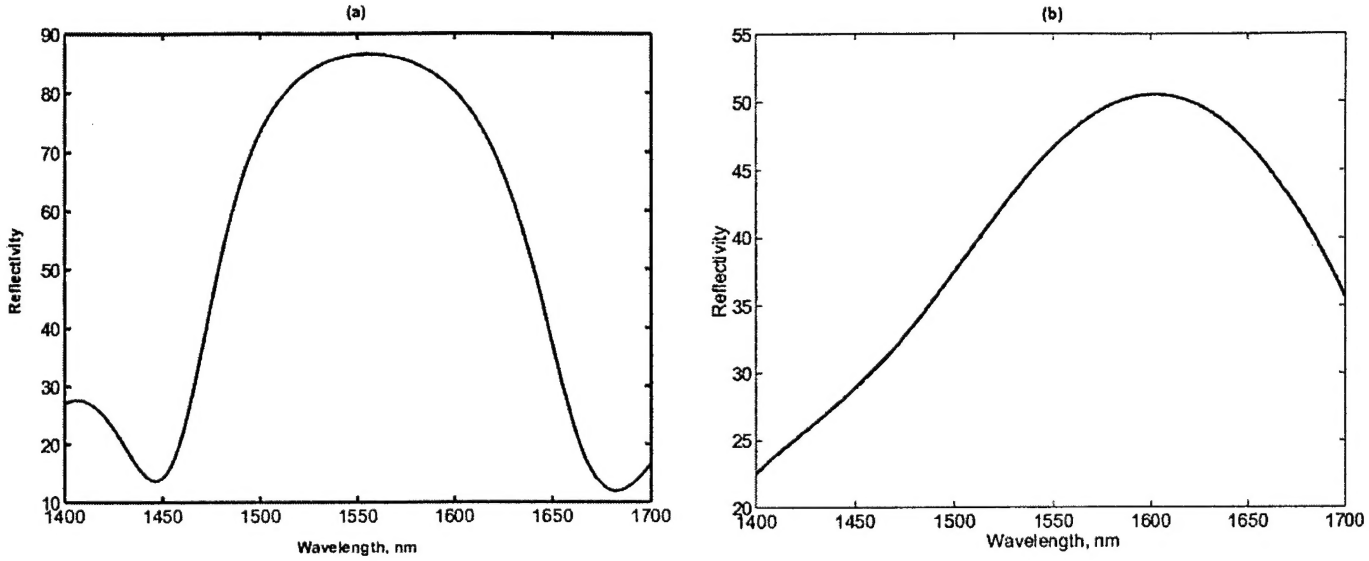

Fig. 5:Measured reflectivity of: (a) 12 periods of n-doped AlGaAs/GaAs DBRs; (b) 5 periods of p-doped AlGaAs/GaAs DBRs.

2.5 Future work

In Phase II of the fabrication, the two InP-based λ-cavity structures will be grown on non-patterned InP substrates and the compressive-strained barriers and tensile-strained wells will be calibrated on InP for lasing at 1550 nm. However, the main theoretical and experimental challenge of the project is tailoring these results in Phase III such that InP-based active regions with same photo-emission spectra can be grown on highly lattice-mismatched patterned GaAs substrates. Photoluminescence data appears to be the best to study the optoelectronic properties of strongly strained InGaAsP quantum wells on patterned GaAs substrates. Obviously, Phase IV will be processing and characterization of the VCSELs experimental benchmark

2.6 Conclusion

Design of 1.30-1.55 μm InGaAsP VCSELs with AlGaAs/GaAs DBRs to be grown on GaAs patterned substrate has been completed. The growth and calibration of the designed bottom DBR and the top DBR mirrors with chirped superlattice graded oxidation layer have been concluded. Growth of the active region cavity on InP substrates, followed by the growth of the full VCSEL structure are in progress.

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